How Tiny Can a Magnetic Bit Be?

Advancing Computer-Disk Technology through Miniaturization

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Every year computer users want more and more disk capacity to store data. Staying at the leading edge of data storage means cramming more information on a disk by making the magnetic bits that represent digital data smaller. In the last two years, for example, the bit size decreased by half, thereby doubling the number of bits per square inch to 1.8 billion (280 million bits/cm^2). By 2005, we would like to see that number soar to 50 billion bits per square inch (7.8 billion bits/cm^2), but finding magnetic materials that can store a bit in an area only 2000 nm^2 and materials that can read the minuscule magnetic signal from such a tiny spot poses major technology challenges.

Microstructures Are the Key

Magnetic data-storage devices, such as the hard disk drive in a personal computer, include a spinning disk to hold the information and a set of read/write heads to put the information in and take it out. Underneath protective coatings, the magnetically active part of today's disk is a granular alloy consisting of cobalt-platinum particles believed to be covered with skins of chromium, boron, and tantalum. Each particle is a tiny magnet. To store a bit, the magnetic field from a write head aligns about 1000 of these particle magnets, forming a magnetic domain. Neighboring domains are separated by transition regions (domain walls) about one or two particles (20 nm) wide. In the disk of 2005 the structure of the domain walls will continue to be especially important, since the sharpness of these boundaries determines the magnetic-field flux that the read head senses.

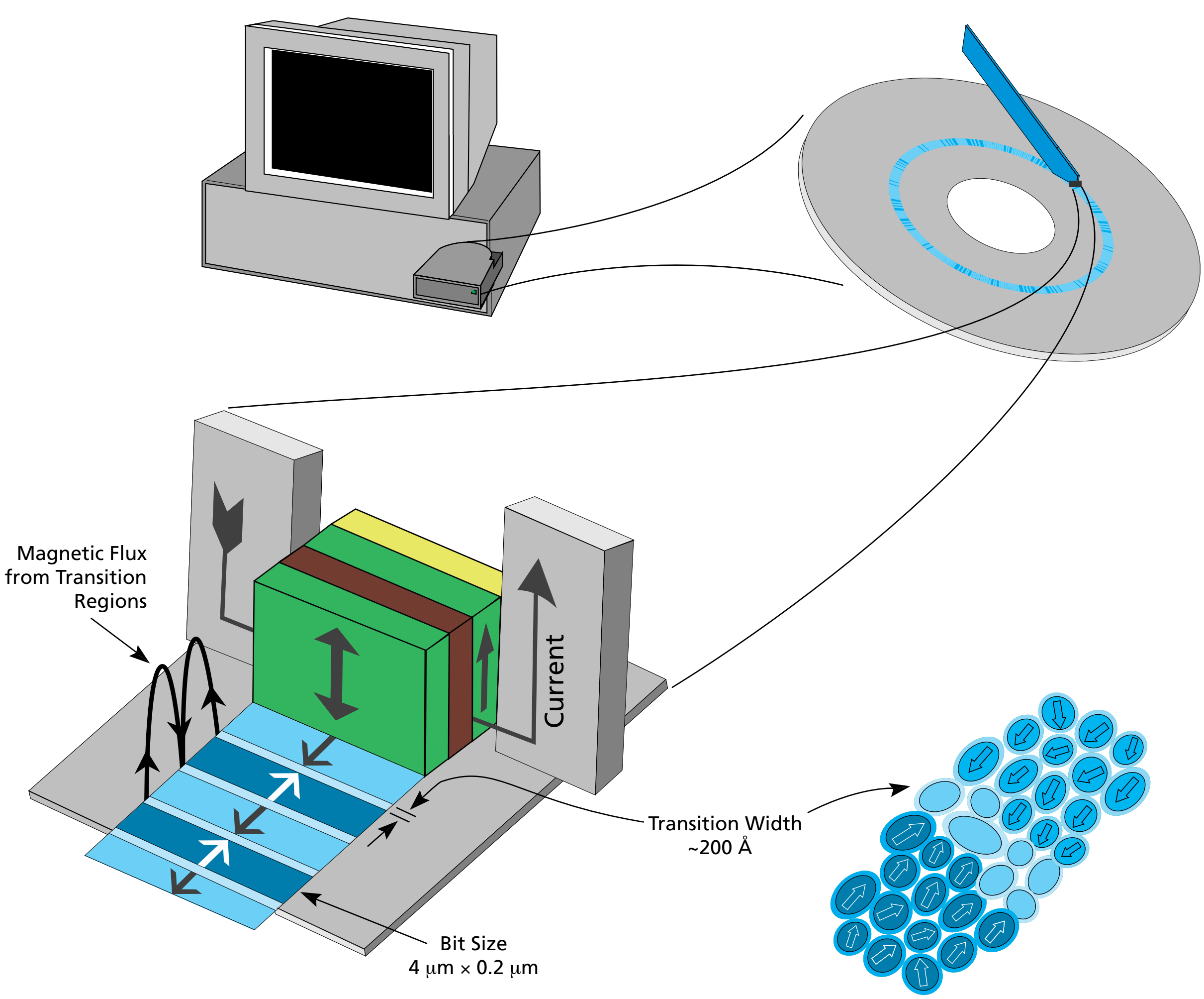
A read head detects the bits by the change in electrical resistance (magnetoresistance) of a nickel-iron alloy as the disk spins rapidly beneath. The next-generation read heads will be based on the more sensitive giant magnetoresistance (GMR) effect in structures comprising alternating magnetic and nonmagnetic metals in layers only a few atoms thick. To design high-performance read heads, we need to know not only the overall response of these layered structures to different magnetic fields but also the magnetism (magnetic moment), chemical bonding, and geometrical arrangement of the atomic elements in each layer. We also need to be sensitive to the interfaces between the layers, since it is the interactions between the layers, not just their separate behaviors, that create the GMR effect.

Circular Polarization Beamlines

No single analytical tool can fulfill every requirement, but we are vigorously exploring the use of circularly polarized x-ray synchrotron radiation at the ALS both to visualize the structure of domains and, ultimately, domain walls in disk materials, and to probe GMR structures layer by layer and element by element.

The net magnetic effect in an alloy depends on the magnetic moments of the constituent atoms and the way they interact with each other. The difference between the absorption of left and right circularly polarized x rays by magnetized materials (magnetic circular dichroism or MCD) measures the magnetic moments of the atoms. Since the wavelength at which x rays are absorbed also identifies the atomic elements and their chemical bonding state, we have much of the information we are searching for. By imaging the dichroism at each point on the surface, we can also visualize the domains and their boundaries.

The ALS is an ideal x-ray source for experiments of this type because it can generate extraordinarily bright circularly polarized beams. We are just completing Beamline 7.3.1.1 with a new electron microscope that will image the electrons ejected from the surface of a sample where x rays are absorbed, thereby allowing us to portray magnetic domains with an expected spatial resolution of 30 nm or better. We are also working with the ALS on the even more powerful Beamline 4.0 complex, which will be equipped with stations for MCD measurements and an advanced electron microscope that will push the resolution for imaging to below the size of individual magnetic particles. The first stage of this beamline will be ready in 1998.



Materials challenges in advanced computer disk technology arise both in the disk itself and in the read head that extracts data from the disk. Ultimately, we would like to be able to investigate the structure of the narrow transition regions between magnetic bits on the disk, since the sharpness of these boundaries determines the magnetic flux that the read head senses by a change in the electrical current flowing through the head. The spin-valve version shown here consists of an antiferromagnetic substrate (yellow) on which two ferromagnetic layers (green) are separated by a nonmagnetic layer (brown). In the read head, we would like to measure the contributions of each atomic element in each layer and the way they interact with each other to generate the overall device behavior.